Fermilab

$\bar{p}$ Note #391

DYNAMICS OF PBAR TRANSFER FROM THE MAIN RING TO THE TEVATRON

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Introduction

This will be a general description of the present design of the reverse injection system which extracts pbars from the Main Ring and transfers them to the Tevatron at 150 Gev. The emphasis will be on the beam dynamics. A list of the required devices and their operating points will also be given.

General Description

The general outline of the system is quite similar to the forward injection system described in UPC-157. Pbars circulating in the Main Ring are kicked onto an extraction orbit by a kicker at E17 (kick angle +450 microrad). For details of this kicker and the Tevatron injection kicker at D48 mentioned below, see pbar note 365. The kicked beam passes through the field region of two standard forward-injection-style Lambertsons (see UPC-157 for details of these magnets), and is pitched down towards the Tevatron. As in the forward injection system, there are two trim dipoles and a lattice matching quadrupole in the transfer line; the beam is then pitched flat at Tevatron height by two more forward-injection-style Lambertsons in the Tevatron, and injected into the Tevatron aperture. It is kicked onto the closed orbit by a kicker at D48 (kick angle -940 microrad).

Betatron Emittance and Momentum Spread

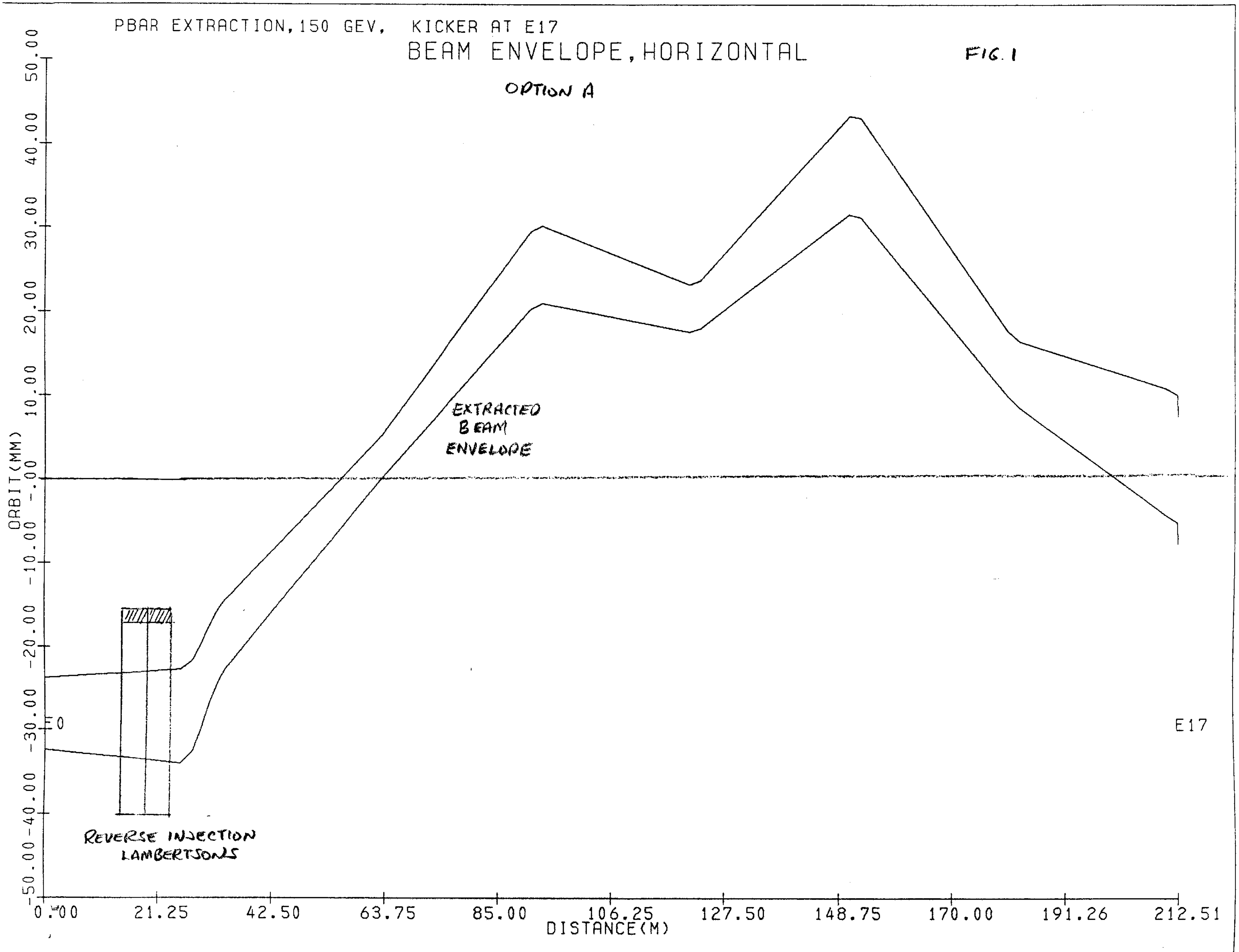
The following calculations have been done for a momentum of 150 Gev/c, using a normalized emittance of 25 pi mm-mrad and a momentum spread of $\pm$ 0.115%. These numbers correspond to 95% of the beam. The momentum spread corresponds to that of a coalesced pbar bunch: see Tev I Design Report, Oct. 83, pg 6-5. The betatron beam width and the dispersion contribution have been added in quadrature. For the Main Ring calculations, the lattice used is the standard lattice (no overpasses) with horizontal tune= 19.4. For the Tevatron, the lattice used for the calculation includes the high beta in sectors D,A, the abort system at CO and the extraction devices at DO. The horizontal tune is also 19.4.

Main Ring Extraction

Two scenarios for extraction from the Main Ring will be discussed. In the first option (A), only the kicker at E17 is used; the 450 microradian kick produces an orbit offset of −28 mm at the extraction point, and the Lambertson septa are placed at roughly −15 mm. Figure 1 shows the extraction orbit from E17 to the Lambertsons, and fig. 2 shows the extracted and circulating beam orbits near the extraction point. There are two possible problems with this scheme. The first is seen in figure 1: the outer edge of the beam reaches +43 mm at E15, which is a fairly large excursion, although in principle well inside the physical aperture. Things may be even worse than this, since the exiting closed orbit at 150 GeV in the Main Ring (see fig. 3) already has a 4−6 mm outward deflection in this area. The second problem is illustrated in fig 4: the 8 GeV beam is so big at the reverse injection Lambertson (where betax is 120 m) that, with the septum at −15 mm, the beam will hit unless it is steered roughly 8 mm out. This can be done, in principle, using the 8 GeV horizontal correction elements at D48, D49, E11 and E13. Alternatively, both of these problems can be eliminated in option B. In this option, we fix the second problem by using the existing D46−E17 bump magnets to generate an inward bump of roughly −8 mm at the extraction Lambertsons during extraction. This allows the Lambertson septa to be moved away from the Main Ring center line by 8 mm, so that the 8 GeV beam has a clear aperture. The first problem is fixed by installing a new 20" bump magnet at E12 in the Main Ring: this allows the excursion of the extraction orbit between E17 and the extraction Lambertson to be reduced by roughly 13 mm. Fig. 5 shows the extracted beam between E17 and the extraction point, with this option; fig. 6 shows the region near the extraction point; and fig. 7 shows the circulating beam, with the orbit bumps on, from D43 to E19.

Transfer Line

The transfer line elements are four Lambertsons, two trims and one quad (the last shared with the forward injection line); they are numbered from the Tevatron to the Main Ring as shown in fig. 8. Figure 9 shows the circulating and extracted beam spots in the Main Ring Lambertsons. Fig. 8 shows the horizontal orbits in the transfer line, relative to the Main Ring and Tevatron center lines. To inject properly into the Tevatron, one must obtain the proper horizontal and vertical position and angle at the point of injection. The proper vertical position and


PBAR EXTRACTION,150 GEV, KICKER AT E17
BEAM ENVELOPE,HORIZONTAL
FIG. 1
OPTION A
EXTRACTED
BEAM
ENVELOPE
REVERSE INJECTION
LAMBERTSONS
E0
E17
ORBIT(MM)
50.00
40.00
30.00
20.00
10.00
-.00
-10.00
-20.00
-30.00
-40.00
-50.00
0.00
21.25
42.50
63.75
85.00
106.25
127.50
148.75
170.00
191.26
212.51
DISTANCE(M)

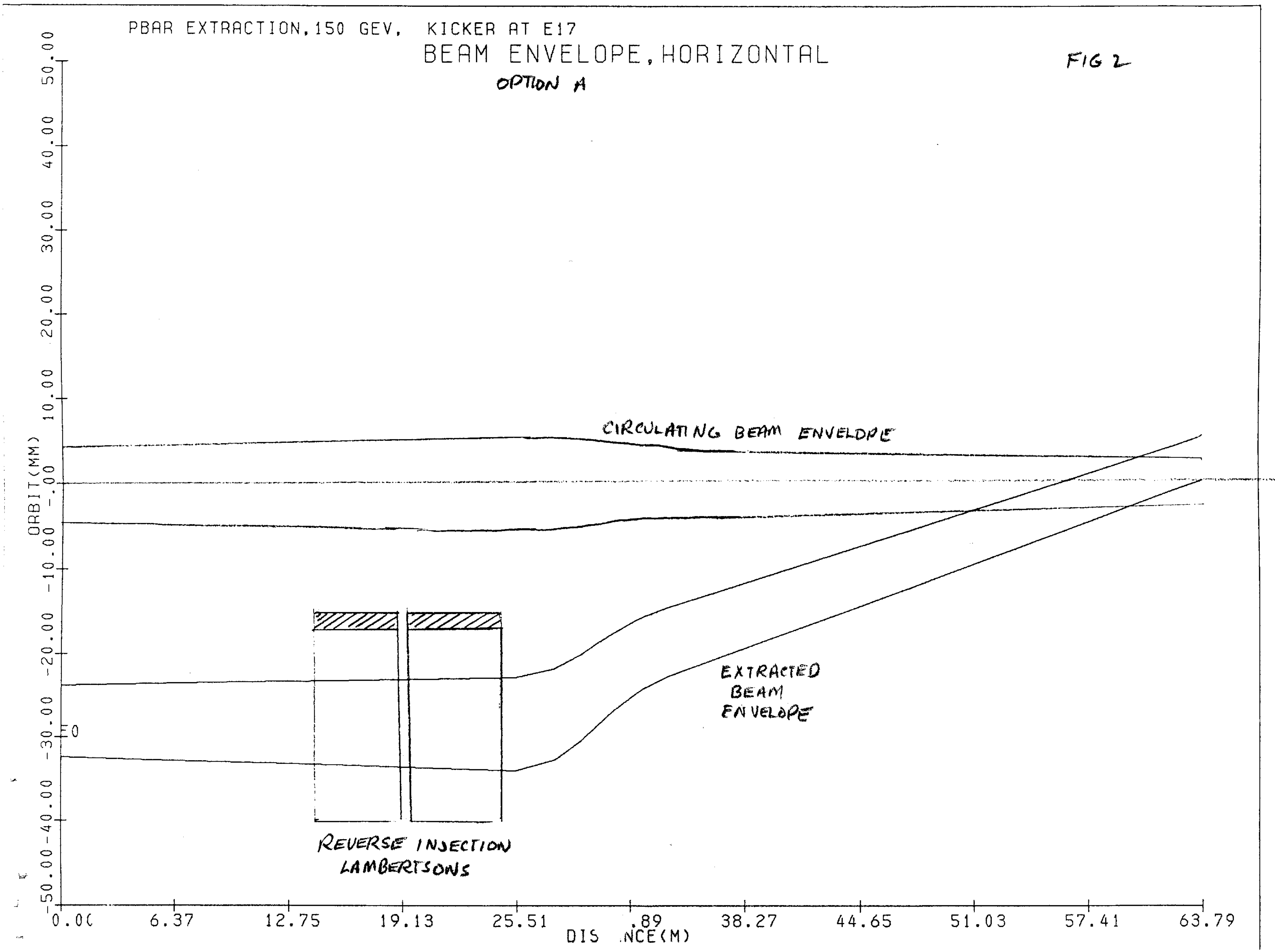

PBAR EXTRACTION,150 GEV, KICKER AT E17
BEAM ENVELOPE,HORIZONTAL
OPTION A
ORBIT(MM)
50.00
40.00
30.00
20.00
10.00
-.00
-10.00
-20.00
-30.00
-40.00
-50.00
E0
CIRCULATING BEAM ENVELOPE
EXTRACTED BEAM ENVELOPE
REVERSE INJECTION LAMBERTSONS
0.0(
6.37
12.75
19.13
25.51
.89
38.27
44.65
51.03
57.41
63.79
DIS NCE(M)

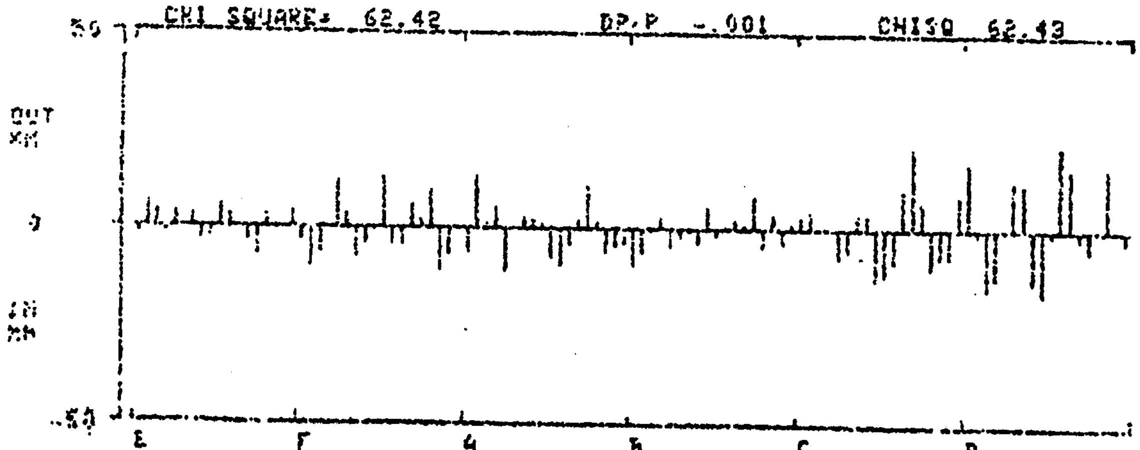
FIG 2

FIGURE 3: EXISTING HORIZONTAL CLOSED ORBIT IN THE MAIN RING

HORIZONTAL CLOSED ORBIT (MM) 05/23/84 1233

FILE 1
UNCALIBRATED
SAMPLE TIME=
3.351 SEC
ENERGY
160 GEV
04/09/84 0950

	E	F	A	B	C	D
11	-1.267	-2.771	-6.334	-9.358	3.322	17.33
13	6.795	-10.41	13.58	-5.959	4.072	-.896
15	3.935	-6.732	1.025	-1.167	-.193	-15.54
17	-1.782	.322	5.01	2.713	.018	-12.45
19	4.053	12.29	-11.37	-5.045	-7.389	.064
22	.791	3.674	.861	-1.763	-5.256	12.82
24	3.697	-7.928	2.97	-.357	4.025	12.15
26	-3.31	-4.172	2.595	-3.685	3.72	-13.69
28	-2.818	-.541	1.483	5.549	-13.91	-16.32
32	5.607	13.16	-7.646	-1.998	-12.07	-1.646
34	3.382	-3.99	-5.598	1.119	-8.584	21.79
36	.275	-4.037	-4.107	2.244	10.56	16.23
38	-2.451	8.416	2.174	1.002	21.34	-2.185
42	-7.459	2.197	11.08	8.737	6.95	-4.764
44	3.158	10.02	1.705	-4.74	-10.16	.861
46	-1.67	-11.04	-6.146	4.374	-7.447	16.12
48	1.168	-6.264	-4.87	-2.498	-7.165	.289
49	4.307	.135	-4.271	1.189	8.865	-2.334



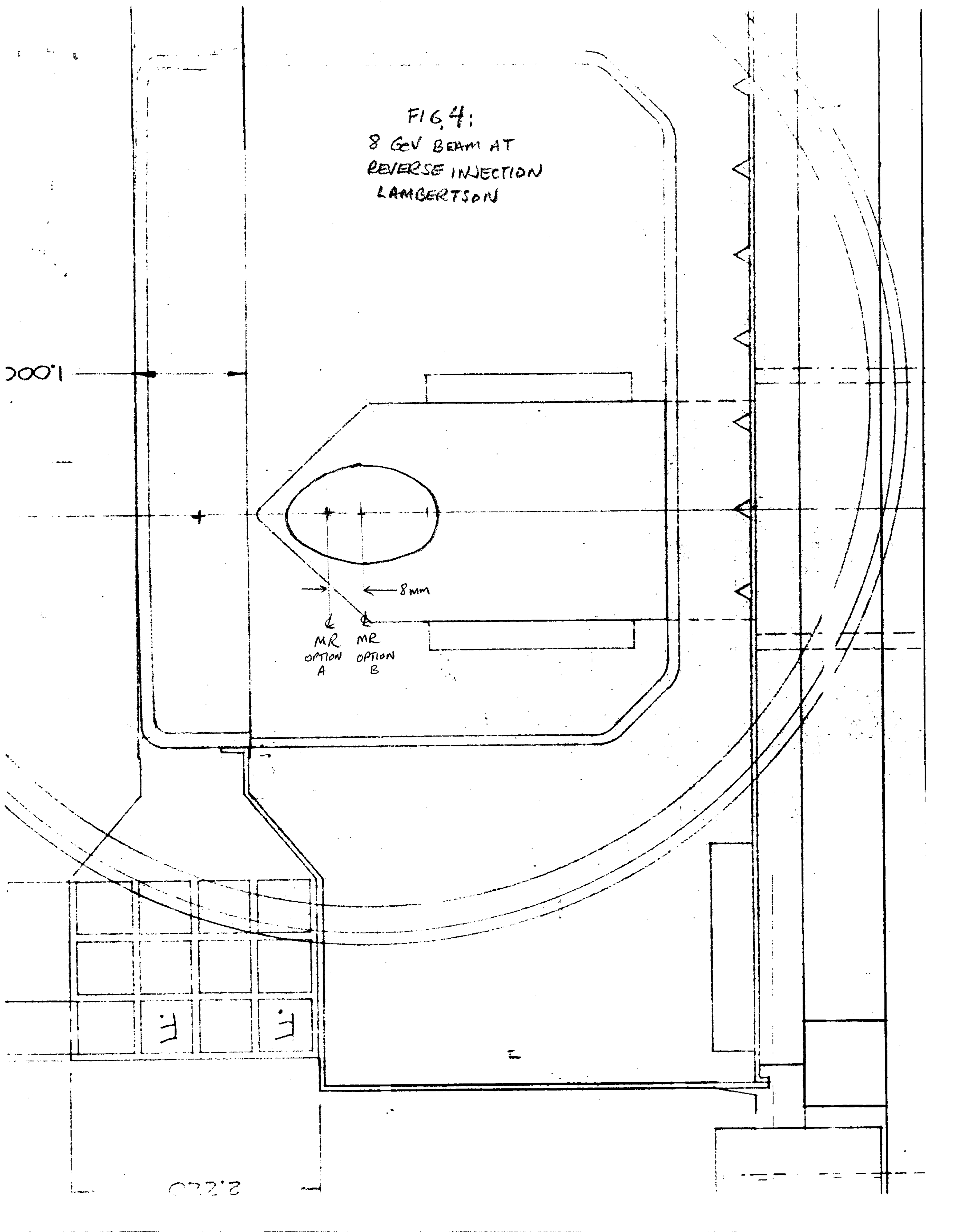
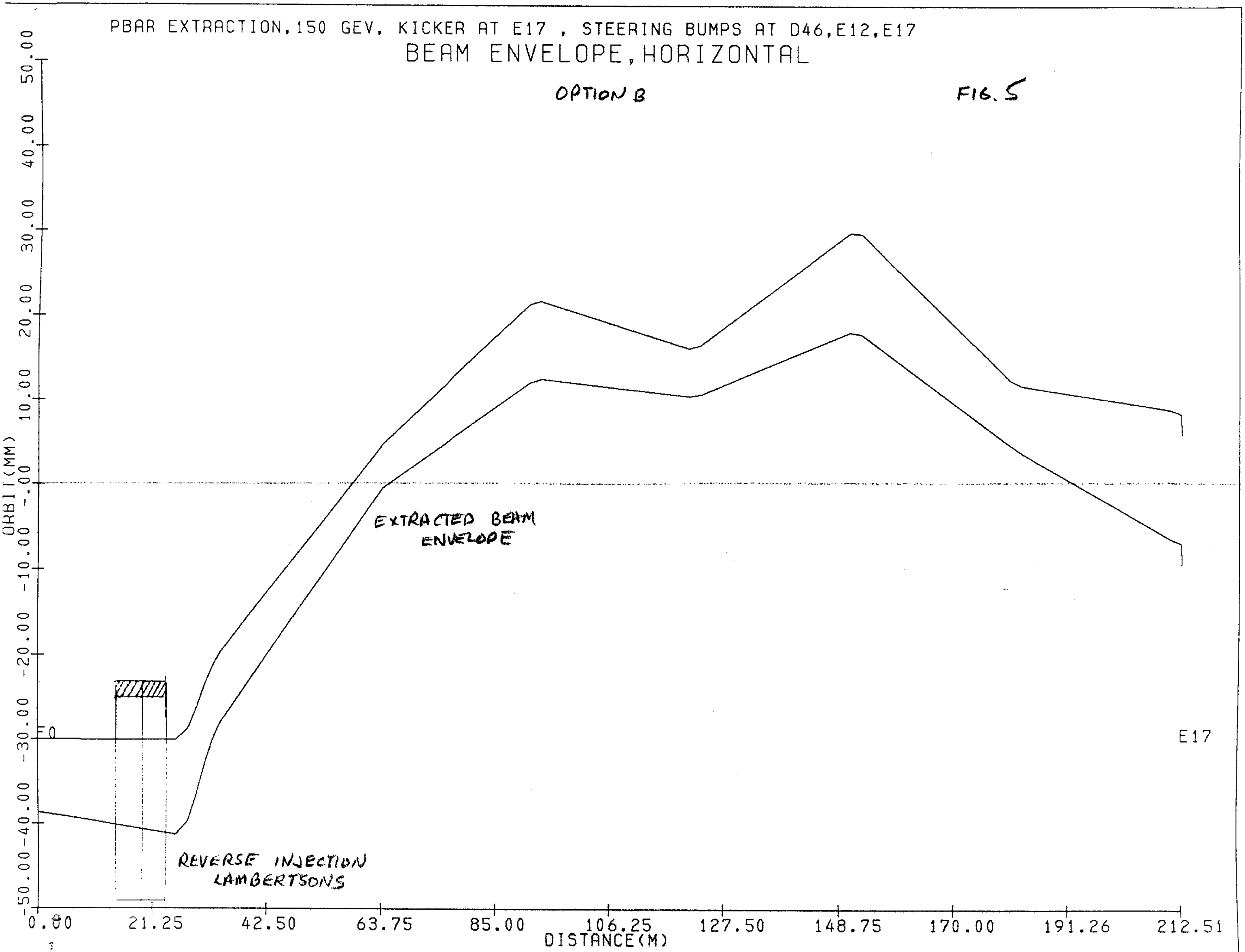
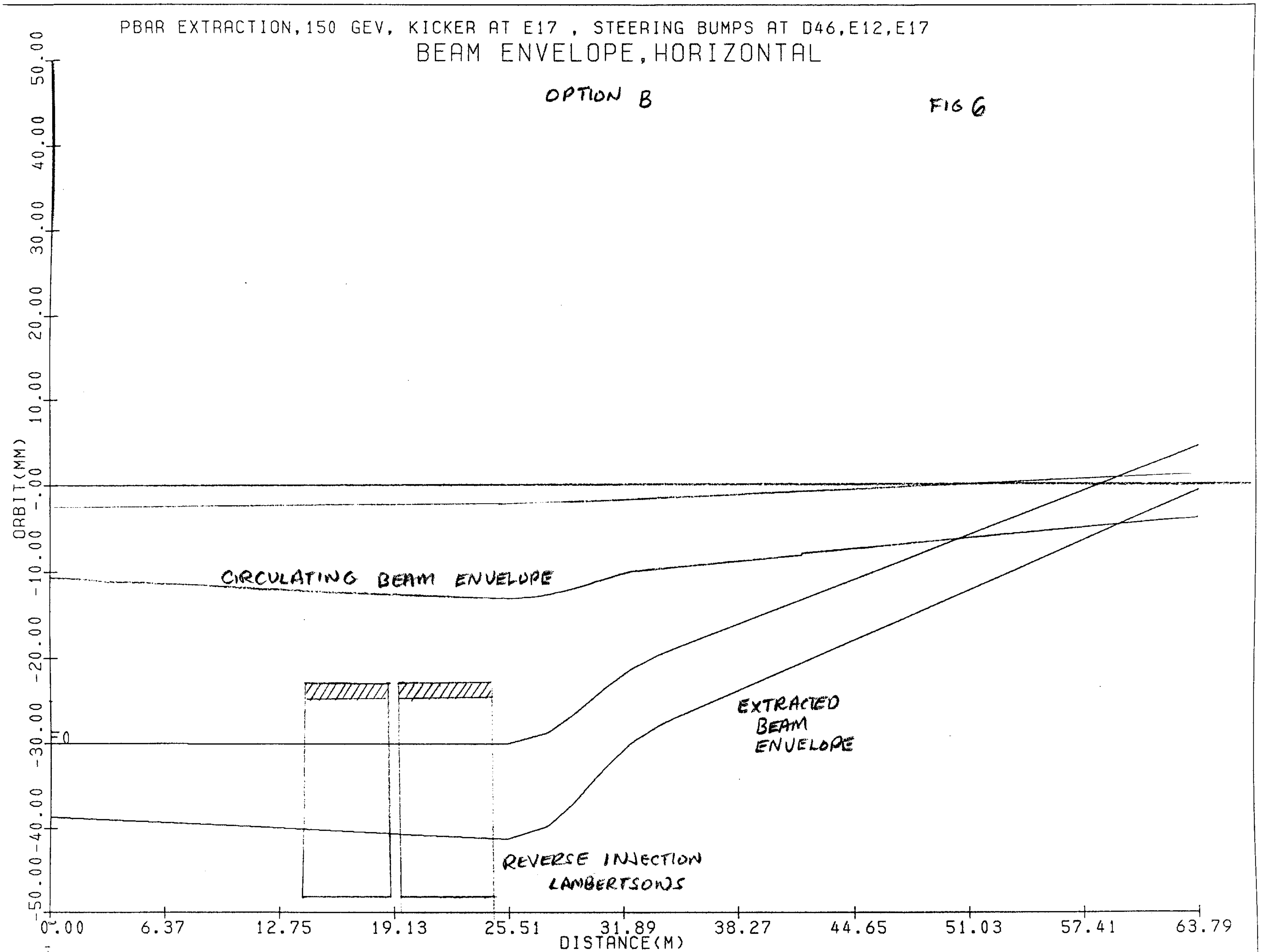


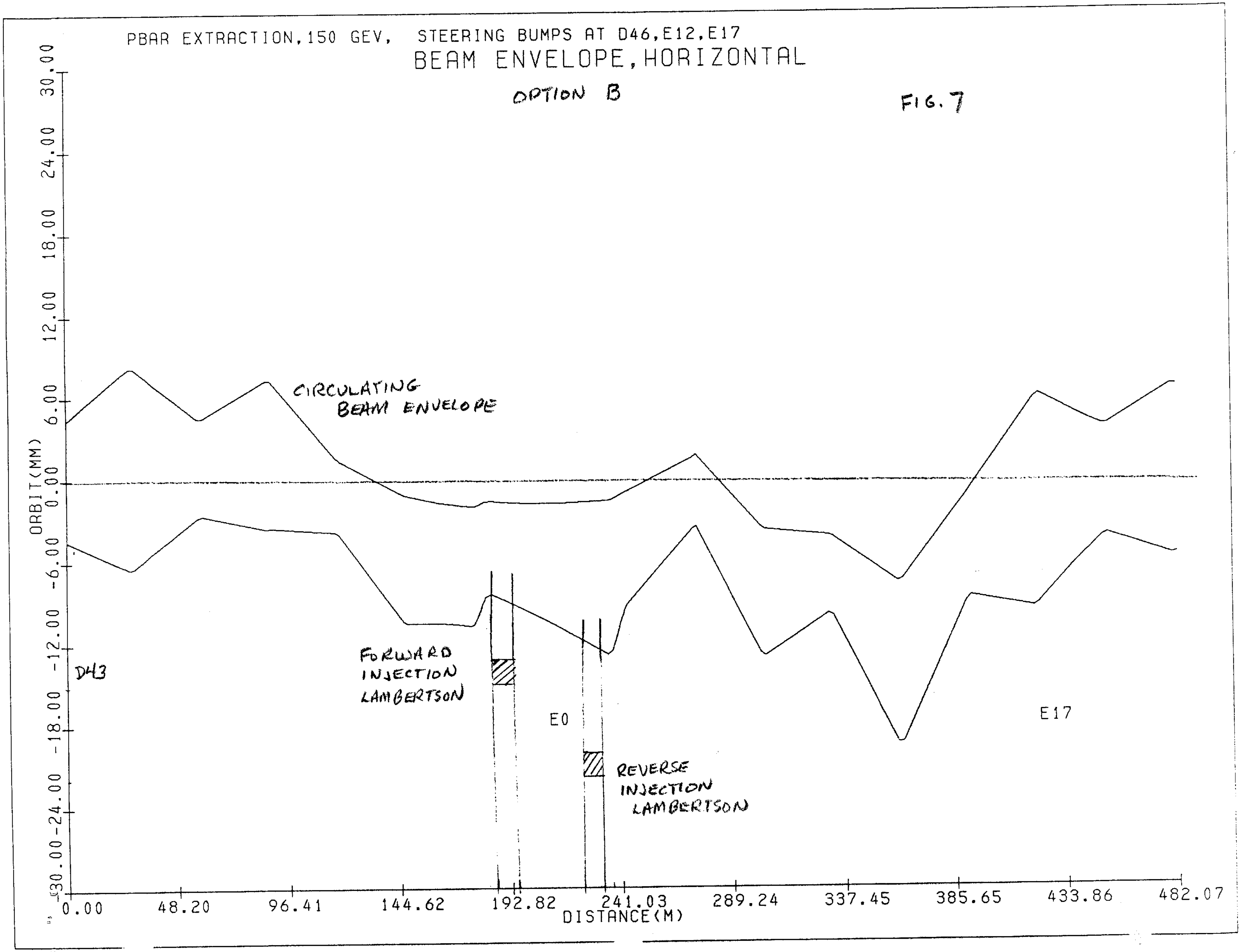
FIG. 4: 8 GeV BEAM AT REVERSE INJECTION LAMBERTSON



PBAR EXTRACTION,150 GEV, KICKER AT E17 , STEERING BUMPS AT D46,E12,E17
BEAM ENVELOPE,HORIZONTAL
OPTION B
ORBIT(MM)
50.00
40.00
30.00
20.00
10.00
-.00
-10.00
-20.00
-30.00
-40.00
-50.00
E0
E17
EXTRACTED BEAM ENVELOPE
REVERSE INJECTION LAMBERTSONS
0.00
21.25
42.50
63.75
85.00
106.25
127.50
148.75
170.00
191.26
212.51
DISTANCE(M)

FIG. 5


PBAR EXTRACTION,150 GEV, KICKER AT E17 , STEERING BUMPS AT D46,E12,E17
BEAM ENVELOPE,HORIZONTAL
OPTION B
ORBIT(MM)
50.00
40.00
30.00
20.00
10.00
-.00
-10.00
-20.00
-30.00
-40.00
-50.00
E0
CIRCULATING BEAM ENVELOPE
EXTRACTED BEAM ENVELOPE
REVERSE INJECTION LAMBERTSONS
0.00
6.37
12.75
19.13
25.51
31.89
38.27
44.65
51.03
57.41
63.79
DISTANCE(M)
FIG 6



PBAR EXTRACTION, 150 GEV, STEERING BUMPS AT D46, E12, E17
BEAM ENVELOPE, HORIZONTAL
OPTION B
CIRCULATING BEAM ENVELOPE
FORWARD INJECTION LAMBERTSON
REVERSE INJECTION LAMBERTSON
D43
E0
E17
ORBIT(MM)
DISTANCE(M)
30.00
24.00
18.00
12.00
6.00
0.00
-6.00
-12.00
-18.00
-24.00
-30.00
0.00
48.20
96.41
144.62
192.82
241.03
289.24
337.45
385.65
433.86
482.07

FIG. 7

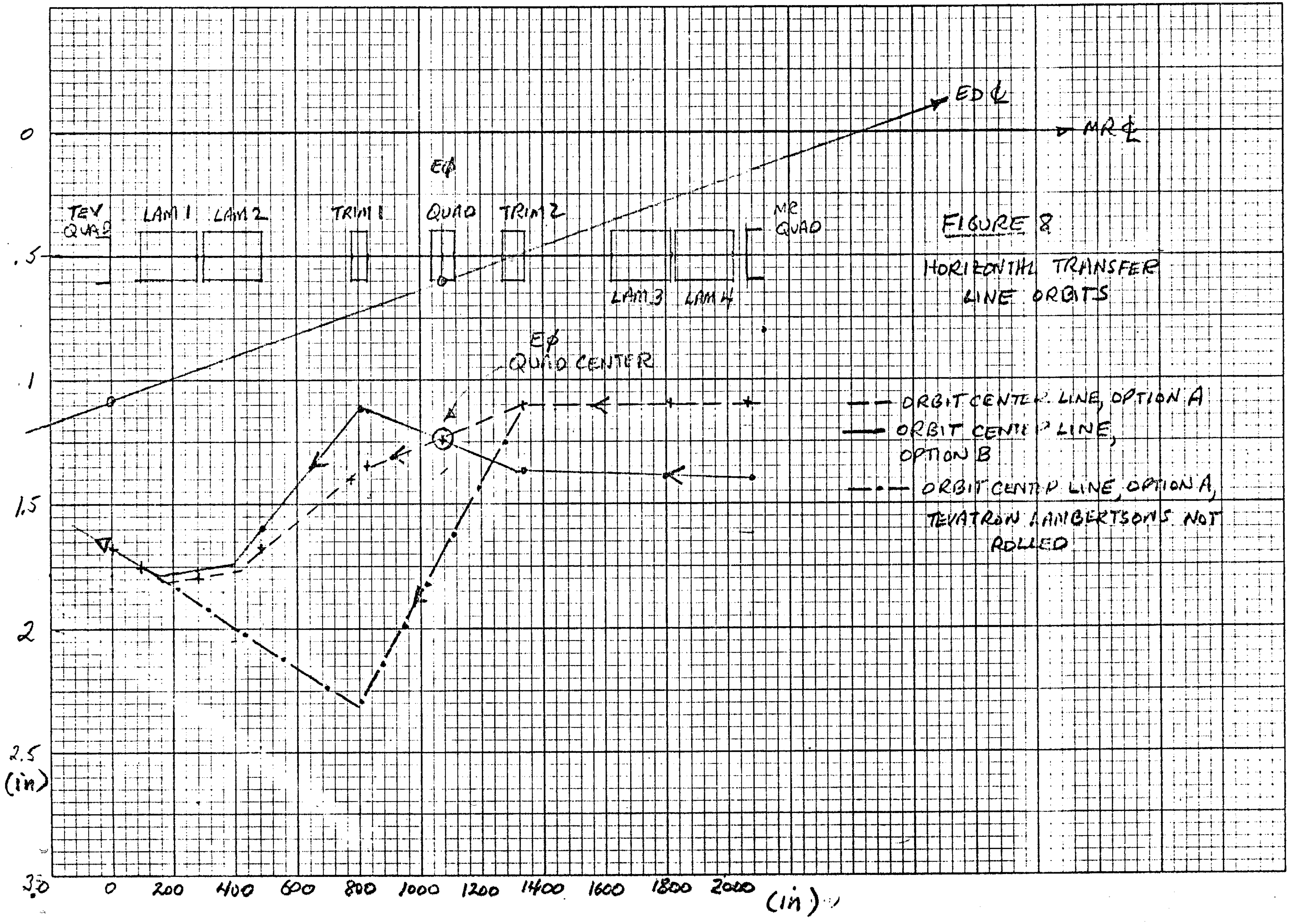


FIGURE 8

HORIZONTAL TRANSFER LINE ORBITS

angle can be obtained with two knobs (the settings of the two sets of Lambertsons, which are equal for a symmetric situation). Two knobs are needed to get the horizontal position and angle right: these are the two trim magnet settings. The line labelled "Tevatron Lambertsons not rolled" in fig. 8 shows the resulting orbit required for matching into the Tevatron: it misses the center of the quad (which is set by the forward injection orbit) by roughly 0.4". Although the aperture is certainly adequate, and the steering introduced by this is small (40 microrad), it would be nice to eliminate it. This can be done by rolling the Tevatron Lambertsons, which provides another horizontal degree of freedom and allows the reverse injected orbit to pass through the center of the lattice matching quad. The resulting orbits are shown in fig. 8, for both options A and B. This procedure also avoids the large trim bending angles (requiring fields > 10 kg) shown in fig. 8 for "Tevatron Lambertsons not rolled". The required roll angles are 5.7 degrees for option A and 7.3 degrees for option B. A 1% shunt would also be required on Lambertsons 3 and 4 to obtain the small required field difference for correct vertical matching.

Tevatron Injection

Figures 10 and 11 show the injected and circulating beam spots in the Tevatron injection Lambertsons. The roll angle illustrated corresponds to 7.3 degrees. The septum of Lambertson 2 is located 15.8 mm from the Tevatron center line; Lambertson 1 is closer, at 9.5 mm. Figure 12 shows the injected and circulating beam envelopes in the injection region. To clear the Lambertson septum after injection, the closed orbit is displaced about 8 mm fromt the Tevatron center line, using horizontal correction dipoles at D48, D49, E11 and E13. Fig. 13 shows the circulating beam envelope from D43 to E17, with this closed orbit distortion in place. The existing injection orbit (see figs. 14 and 15) has a similar bump of about 6.3 mm at injection, which extends through D48 to D46. The dynamics of injection onto this orbit would be very similar to the injection scheme described above, except that the bump is smaller and the injection angle increases from −1100 microrad to −1200 microrad. The resulting impact on the transfer line (for Main Ring extraction option A) would be an increase of the required Lambertson roll to 6.6 degrees and a 40% increase in the field required in trim 1.

FIG. 9 MAIN RING LAMBERTSONS

CIRCULATING AND EXTRACTED BEAM SPOTS

A - UPSTREAM LAM 4
B - DOWNSTREAM LAM 4
C - UPSTREAM LAM 3
D - DOWNSTREAM LAM 3

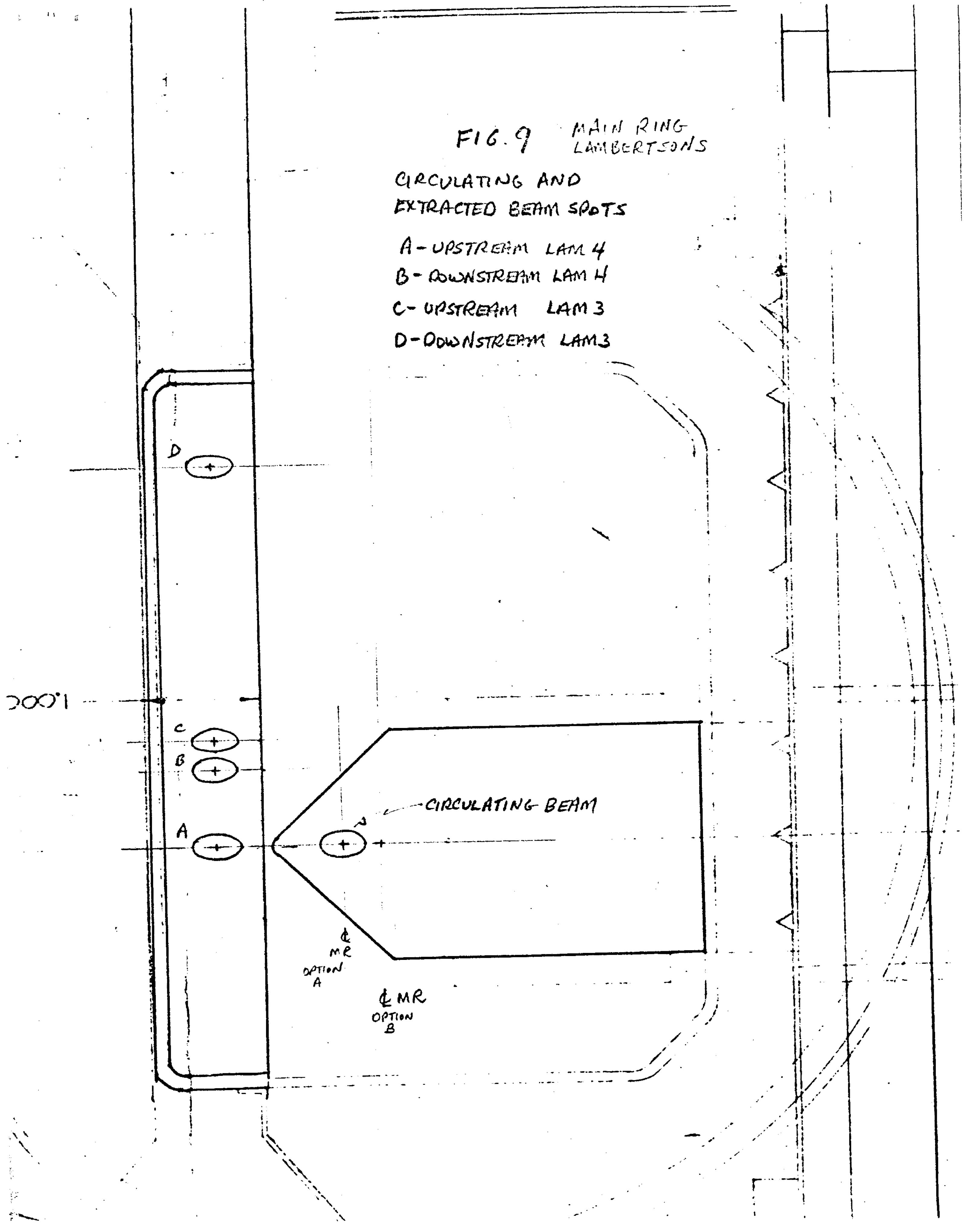


FIG. 10

LAMBERTSON 2
INJECTED, CIRCULATING BEAMS

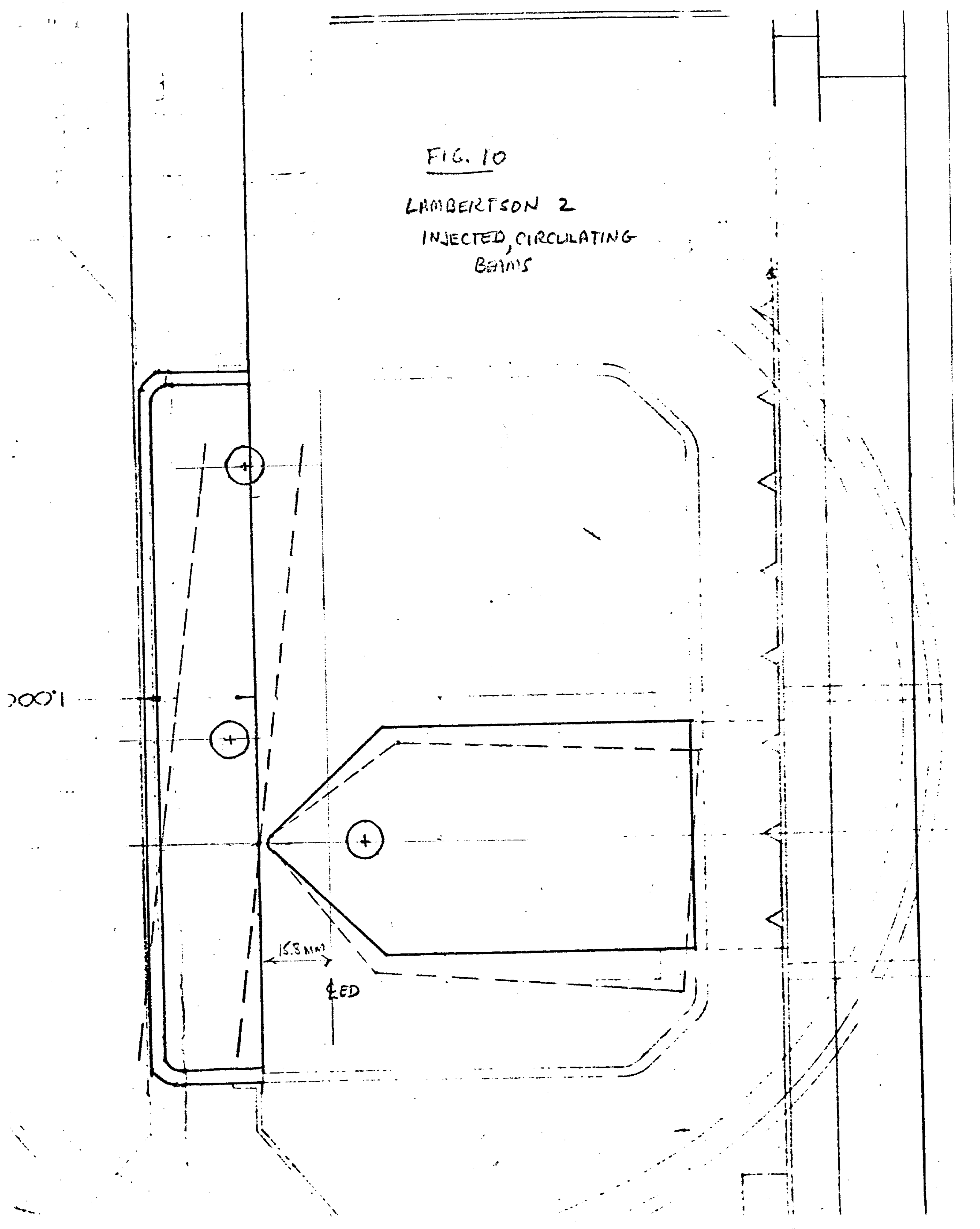
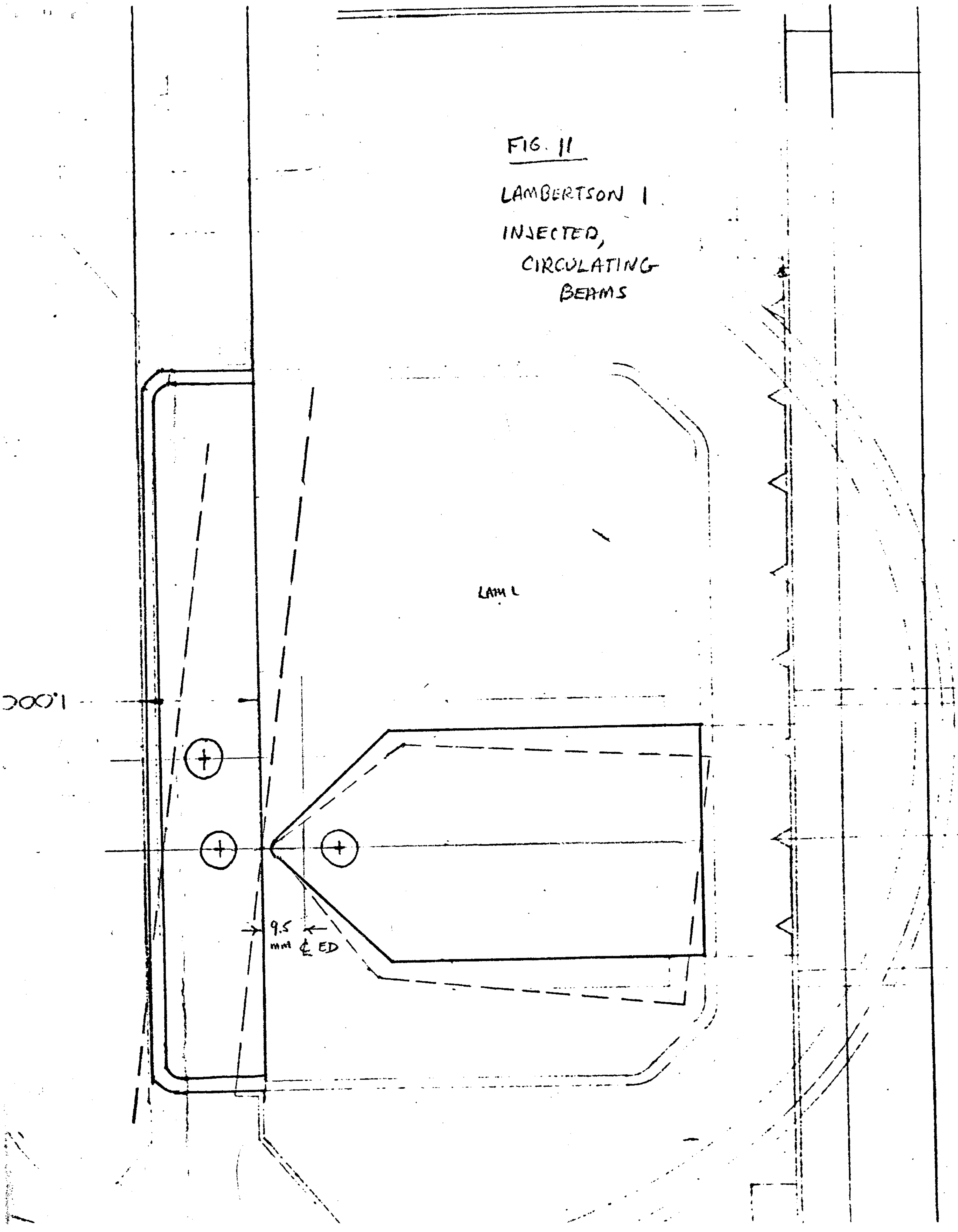
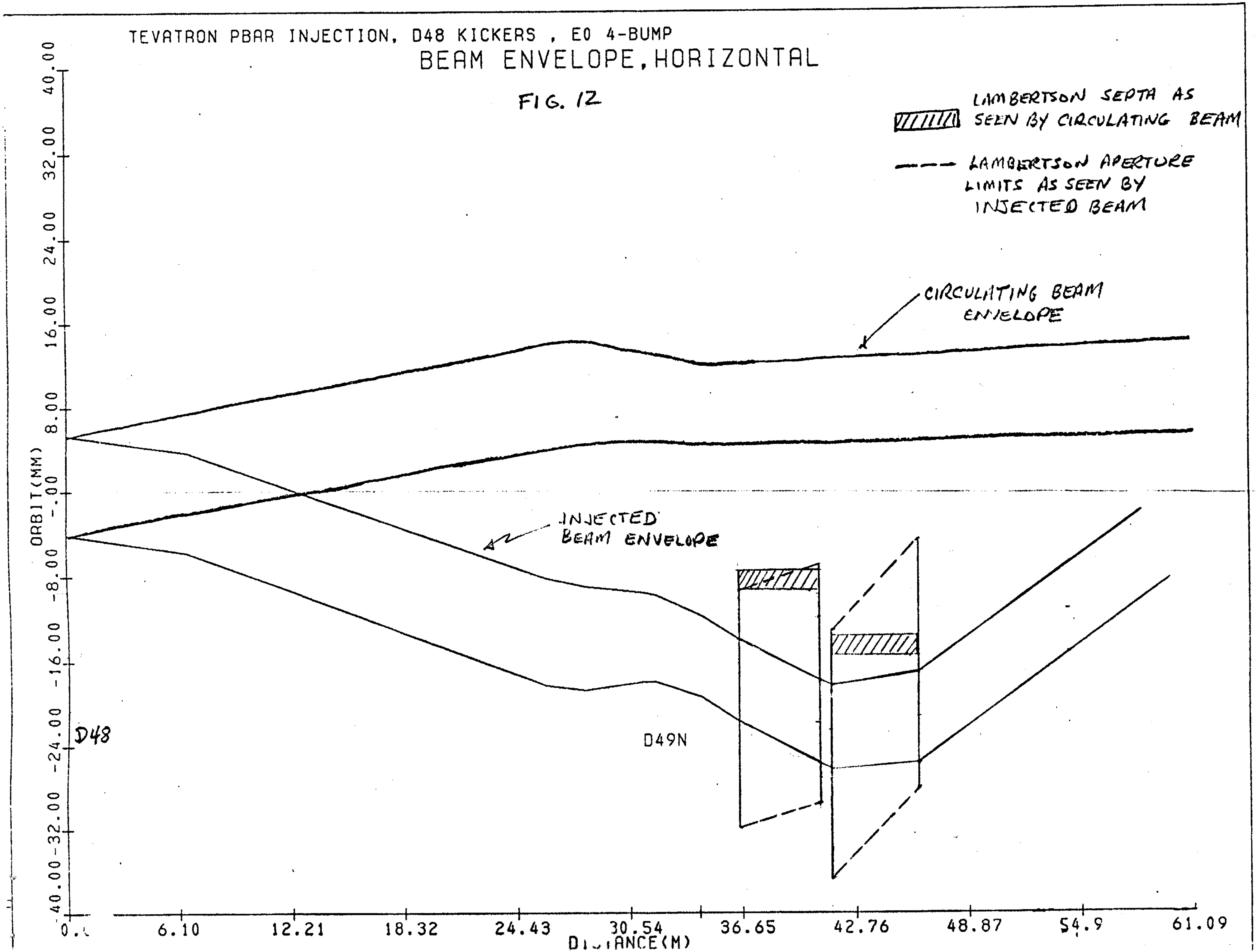


FIG. 11

LAMBERTSON 1

INJECTED, CIRCULATING BEAMS



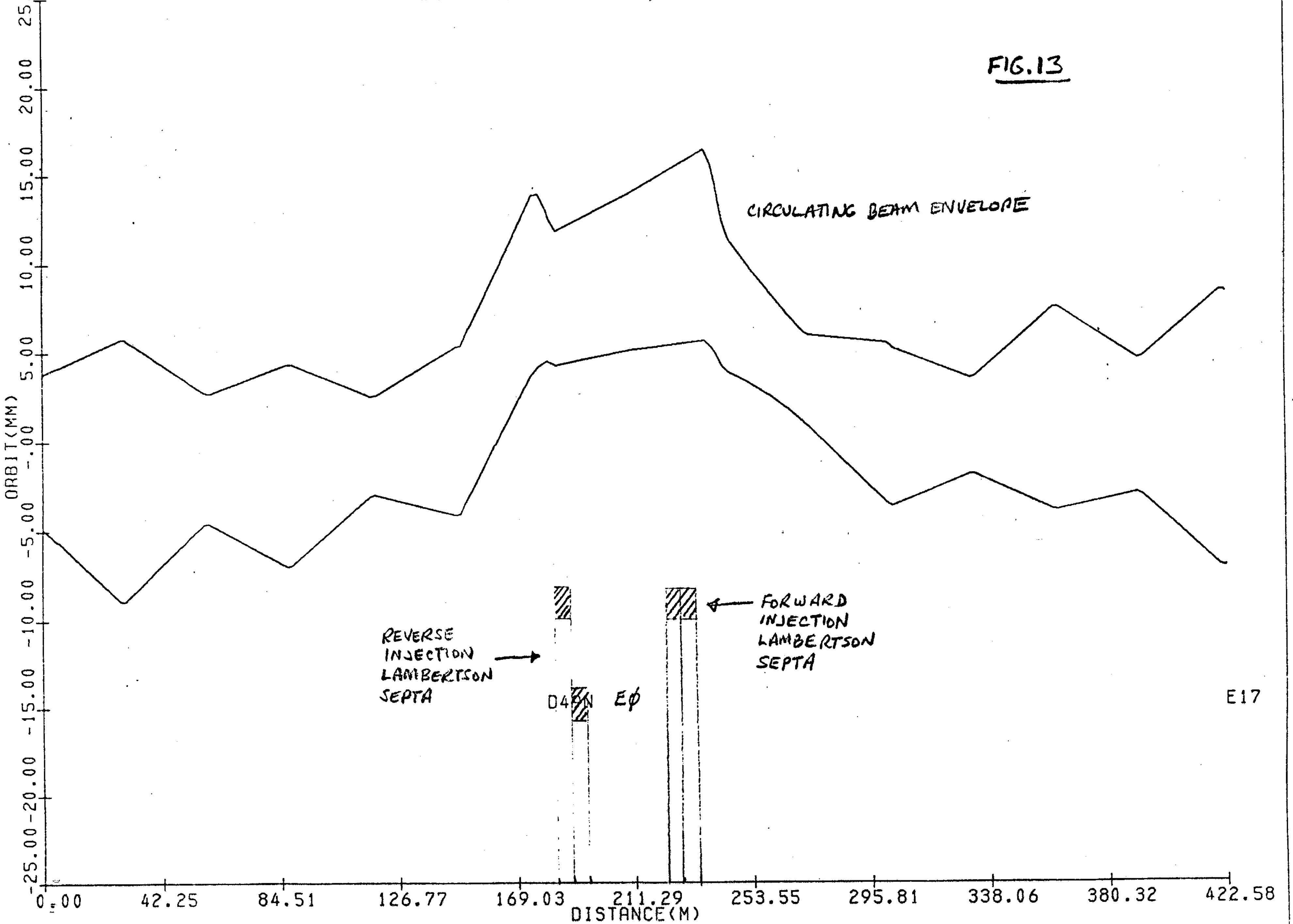


TEVATRON PBAR INJECTION, D48 KICKERS , E0 4-BUMP
BEAM ENVELOPE,HORIZONTAL
FIG. 12
LAMBERTSON SEPTA AS SEEN BY CIRCULATING BEAM
LAMBERTSON APERTURE LIMITS AS SEEN BY INJECTED BEAM
CIRCULATING BEAM ENVELOPE
INJECTED BEAM ENVELOPE
D48
D49N
ORBIT(MM)
40.00
32.00
24.00
16.00
8.00
-.00
-8.00
-16.00
-24.00
-32.00
-40.00
6.10
12.21
18.32
24.43
30.54
36.65
42.76
48.87
54.9
61.09

TEVATRON PBAR INJECTION, E0 4-BUMP

BEAM ENVELOPE, HORIZONTAL

FIG. 13



E17

FIG. 14 INJECTION CLOSED ORBIT.

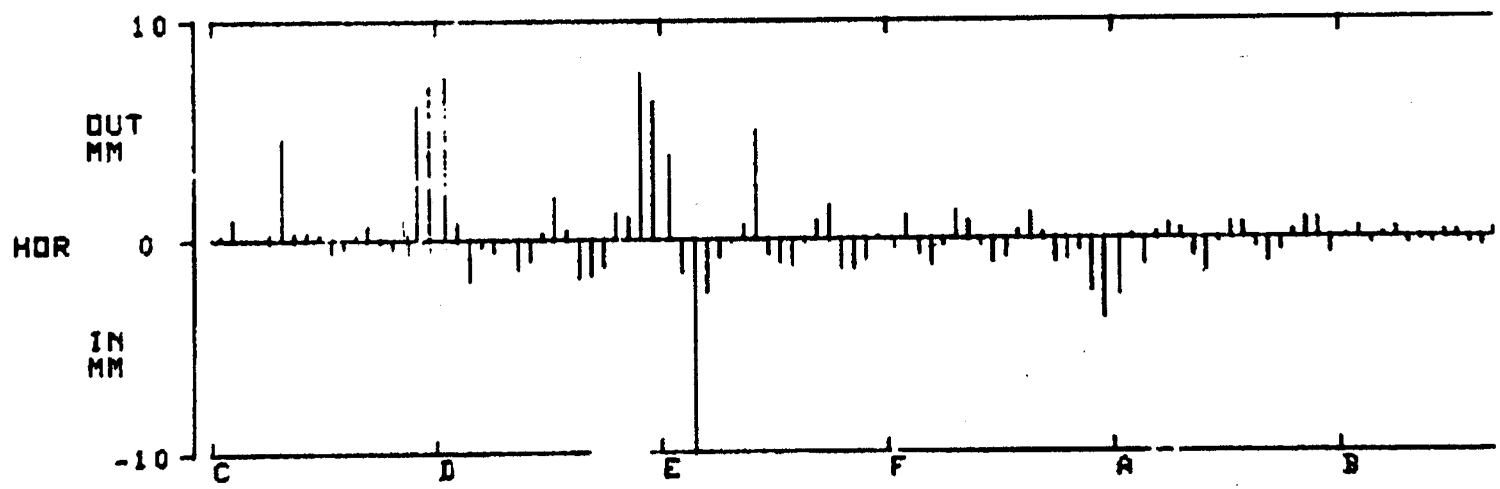
DISPLAY FRAME 4.007

TAKEN 05/21/84 22471 02

(MM) 05/21/84 22471 4

	C	D	E	F	A	B
11	.17	7.45	3.83	-.43	-2.6	.04
13	.87	.78	-1.5	1.01	.09	.43
15	-.04	-1.89	-11.64	-.65	-1.23	-.32
17	-.03	-.29	-2.46	-1.25	.2	.1
19	NOBEAM	-.58	-.84	-.32	.58	.38
22	4.58	-.03	-.1	1.29	.36	-.34
24	.22	-1.45	.59	.76	-.81	-.18
26	.27	-1.01	4.92	-.25	-1.48	-.31
28	.14	.27	-.7	-1.18	-.09	.22
32	-.5	1.94	-1.14	-.78	.67	.2
34	-.38	.41	-1.29	.34	.63	-.27
36	.19	-1.82	-.19	1.09	-.41	-.39
38	.68	-1.71	.83	.23	-1.02	.25
42	-.1	-1.22	1.46	-1.1	-.59	.3
44	-.41	1.17	-1.32	-.97	.3	-.12
46	-.03	1.01	-1.34	-.6	.83	-.59
48	6.08	7.6	-1.01	-2.47	.83	-.16
49	6.99	6.34	.03	-3.66	-.71	0

RMS (MM) = 2.22 DP/P (%) = .0091 MOM CORR RMS = 2.2



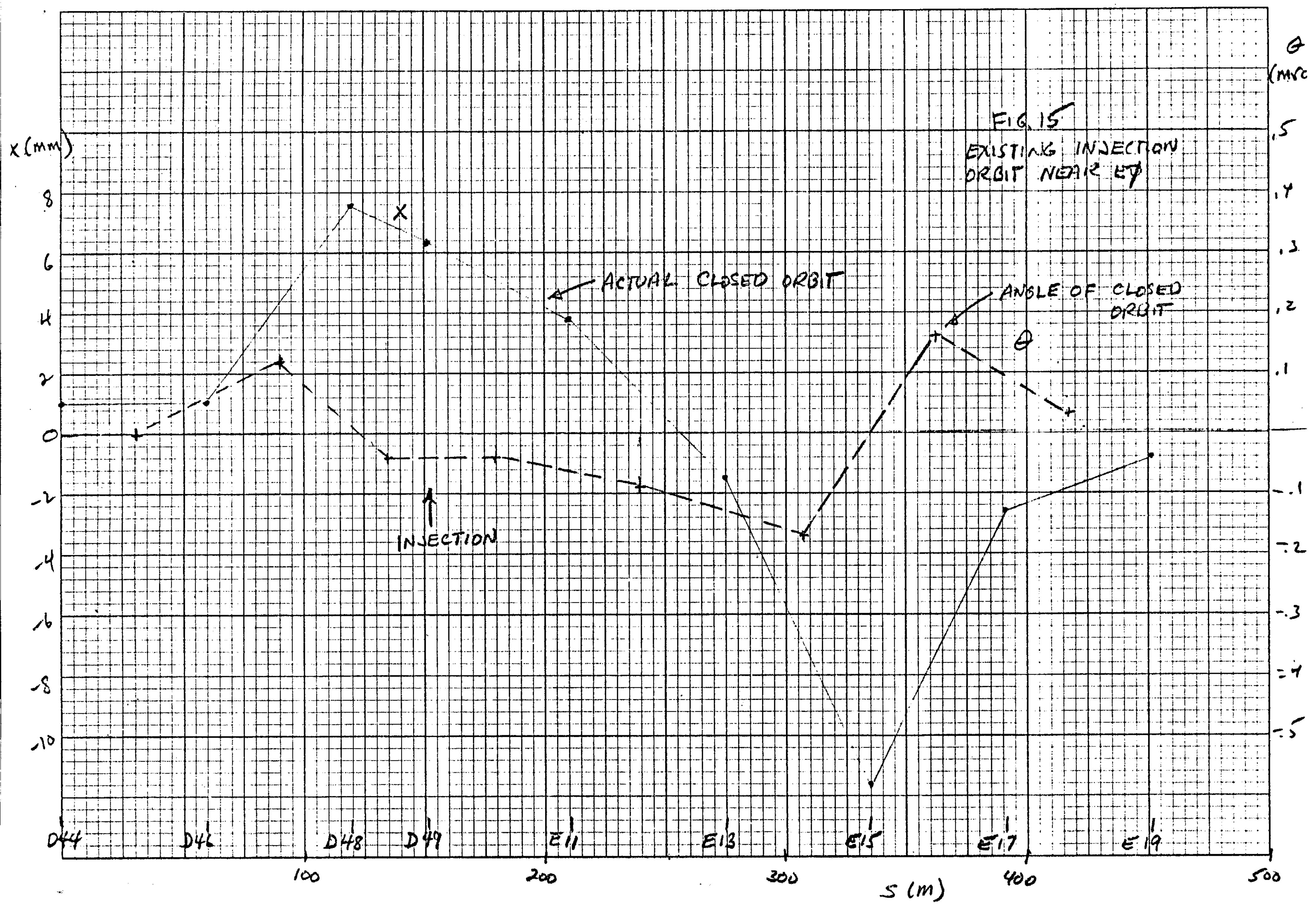
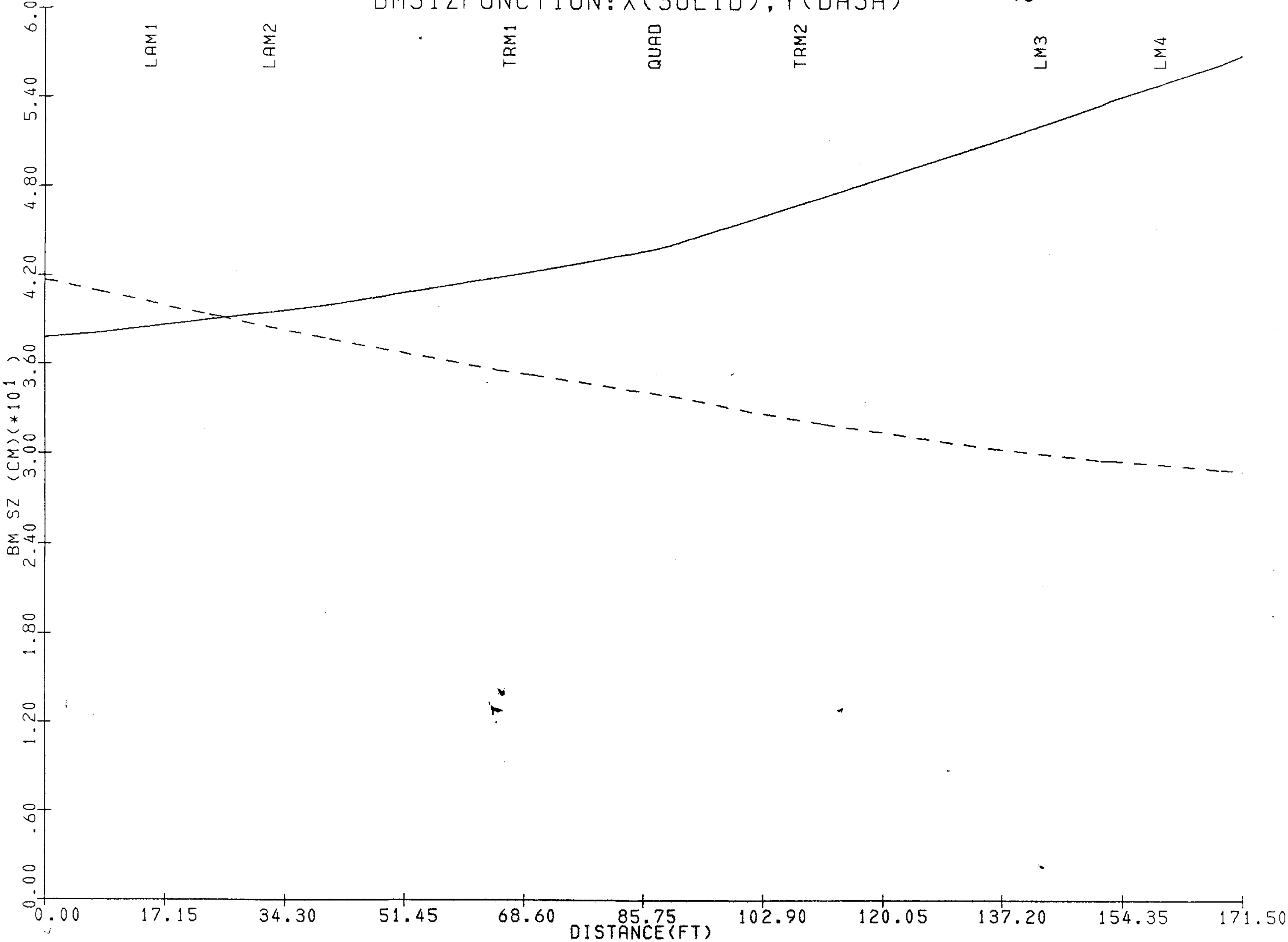


FIG. 15
EXISTING INJECTION ORBIT NEAR E7
X (mm)
θ (mrad)
S (m)
X
θ
ACTUAL CLOSED ORBIT
ANGLE OF CLOSED ORBIT
INJECTION
D44
D46
D48
D49
E11
E13
E15
E17
E19
100
200
300
400
500

"E0 TRANSFER LINE, TEVATRON TO MAIN RING, (LATT FUNC)

BMSIZFUNCTION:X(SOLID),Y(DASH)

FIG. 16



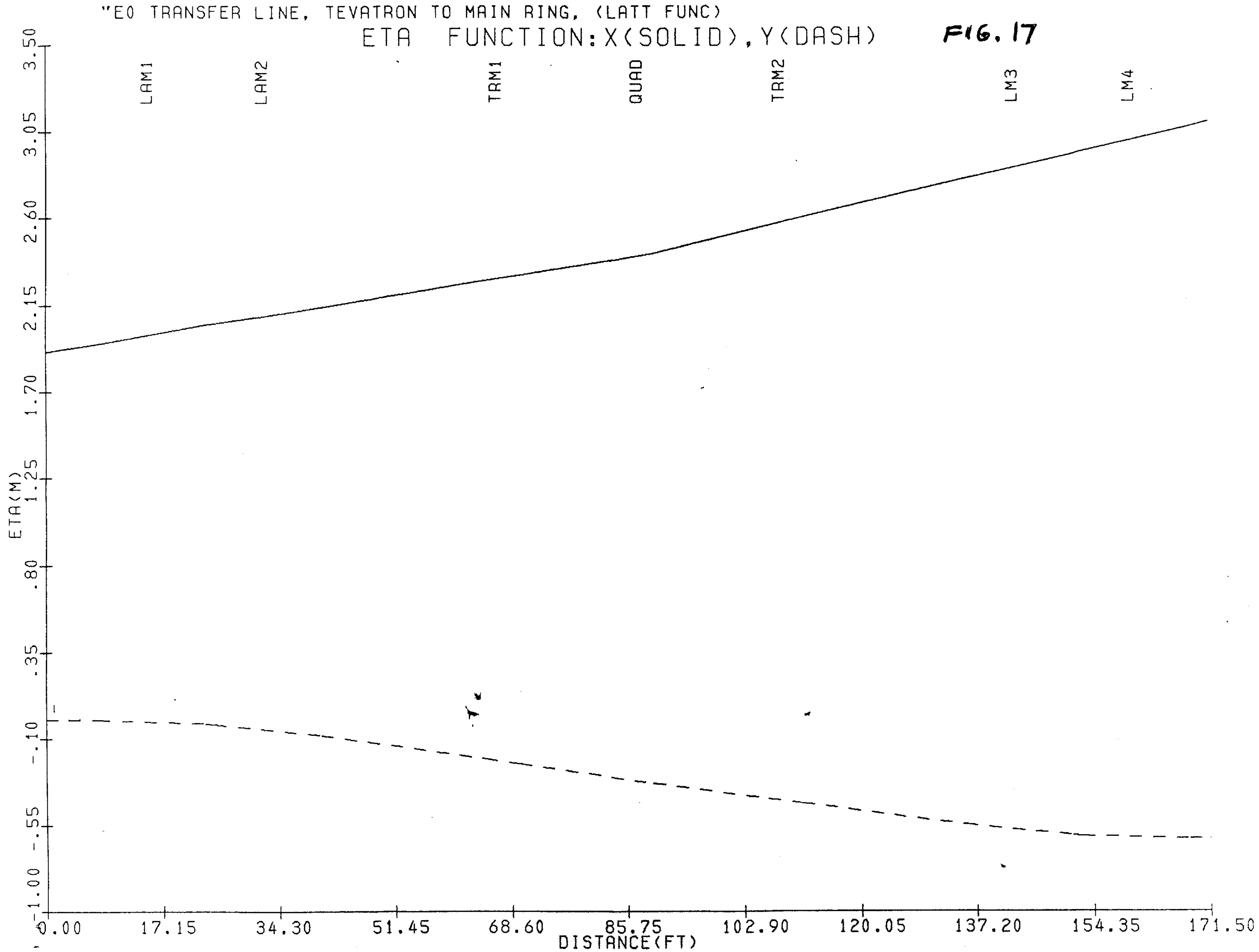

"E0 TRANSFER LINE, TEVATRON TO MAIN RING, (LATT FUNC)
ETA FUNCTION:X(SOLID),Y(DASH)
LAM1
LAM2
TRM1
QUAD
TRM2
LM3
LM4
ETA(M)
3.50
3.05
2.60
2.15
1.70
1.25
.80
.35
-.10
-.55
-1.00
0.00
17.15
34.30
51.45
68.60
85.75
102.90
120.05
137.20
154.35
171.50
DISTANCE(FT)

FIG. 17